FABRICATION PARAMETERS DEPENDENT MORPHOLOGY VARIATION OF SILICON THIN FILM

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Abstract. Achieving two dimensional quantum structure of silicon with well-defined tuneable morphology is an outstanding issue. We present the preliminary results on fabrication parameters dependent silicon thin film production using VHF-PECVD method. Five samples are prepared on Si(100) substrate with gold (Au) catalyst by adjusting different parameters such as deposition time, temperature and the flow of precursor gas. The samples morphology are analysed using FESEM. The results reveal that the silicon thin film appear to be smooth and crystal-like after an enormous amount of hydrogen is inserted together with the precursor gas (silane) during the deposition process. More interestingly, the films exhibit silicon nanowires as the deposition time is increased up to 1 hour. This morphological transformation is attributed to the vapour-liquid-solid (VLS) mechanism related to the deposition process. Our results may contribute towards the development of nanosilicon based optoelectronics.

Keywords VHF-PECVD; FESEM; nanowire; VLS

1.0 INTRODUCTION

Nowadays, the usage of Plasma Enhanced Chemical Vapour Deposition (PECVD) technique in producing nanostructured materials is relatively common

among the material scientists and engineers. Many attempts are made in order to fabricate the desired nanostructured material such as nanowell, nanotube and nanowire. The growing interest towards these kinds of materials is primarily due to their excellent characteristics compared to their bulk conterparts. We focused more on the production of silicon (Si) nanowires (NWs) using very high frequency (VHF) PECVD. Silicon nanowires became attractive due to their widespread applications in microelectronics while semiconducting nanowires have recently been the subject of great scientific and technological interest for their excellent electrical, optoelectronics, mechanical and chemical features [1-4]. For example, Si-NWs is reported to possess unique macroscopic optical properties and yields significantly reduced optical reflection over the full spectrum above the band-gap, as well as reduced transmission for wavelengths greater than ~700 nm for 10 μm long wires [5].

Fabricating nanowire using PECVD requires metal catalyst in its procedure. This would allow controlled, selective growth by pre-patterning the catalyst on the substrates [6]. Up until now, various metals such as Au, Fe, Pd, Pt, W, Ti and Ga are used as catalyst [7-12]. Among all these metals, Ga is the most favourable catalyst for low temperature synthesis since Ga-Si system possesses a very low eutectic temperature. However, we choose Au as catalyst to avoid the possible contamination arises from Ga [11]. Si and Au catalyst combination does not form a silicide and the eutectic temperature of Au/Si is 363 ºC which is relatively lower. This makes Au a suitable catalyst because it gives low temperature growth and does not leave a fast diffusing impurity [12]. The morphology of synthesized samples is scrutinized via FESEM measurements.

2.0 EXPERIMENTAL

The experimental process had begun with substrate cutting and cleaning. The silicon (100) wafer as substrate was cut into small squares of 1 cm ×1 cm dimension before they were cleaned in an ultrasonic bath. The samples were then immersed in HF solution for 10 minute to eliminate any native oxide from the surface.

The deposition of small drops of gold (Au) colloids on the sample was performed using radio frequency magnetron sputtering for 20 s. Au is used as catalyst to assist the growth of Si-NWs on the substrate via VLS mechanism. The Au coated substrate is then placed on a sample holder in the VHF-PECVD's chamber. Then, the chamber was evacuated and pumped down to ultra-high vacuum (~20 mTorr). While waiting for the chamber to reach the desired temperature (Table 1), 300 sccm of hydrogen was injected into the chamber. The presence of hydrogen allows in cleaning the substrate surface. After the desired temperature is achieved, 10 sccm of silane is inserted into the chamber together with the hydrogen to reduce the possibility of SiO_2 formation [13]. The power was set up at constant value of 24 Watt. The selection of deposition parameters are listed in Table 1.

Table 1: Deposition parameters of sample preparation.

Sample Code	Hydrogen (sccm)	Silane (sccm)	Temperature (ºC)	Deposition time (min.)
S1	0	5	300	10
S2	0	5	400	10
S3	300	5	500	10
S4	300	10	500	30
S5	300	10	500	60

First sample is acquired to calibrate the sample preparation method. Therefore all parameters were set to their minimum value. No hydrogen was inserted. Only 5 sccm of silane at 300 ºC temperature was injected and deposition was performed only for 10 minutes. The as-prepared samples were analysed using Hitachi SU8020 Field Emission Scanning Electron Microscope located at Central laboratory, Universiti Teknologi Malaysia.

3.0 RESULTS AND DISCUSSION

Figure 1(a)-(e) shows the FESEM images of all as-synthesized samples with 50 000 × magnifications and 2kV of voltage.

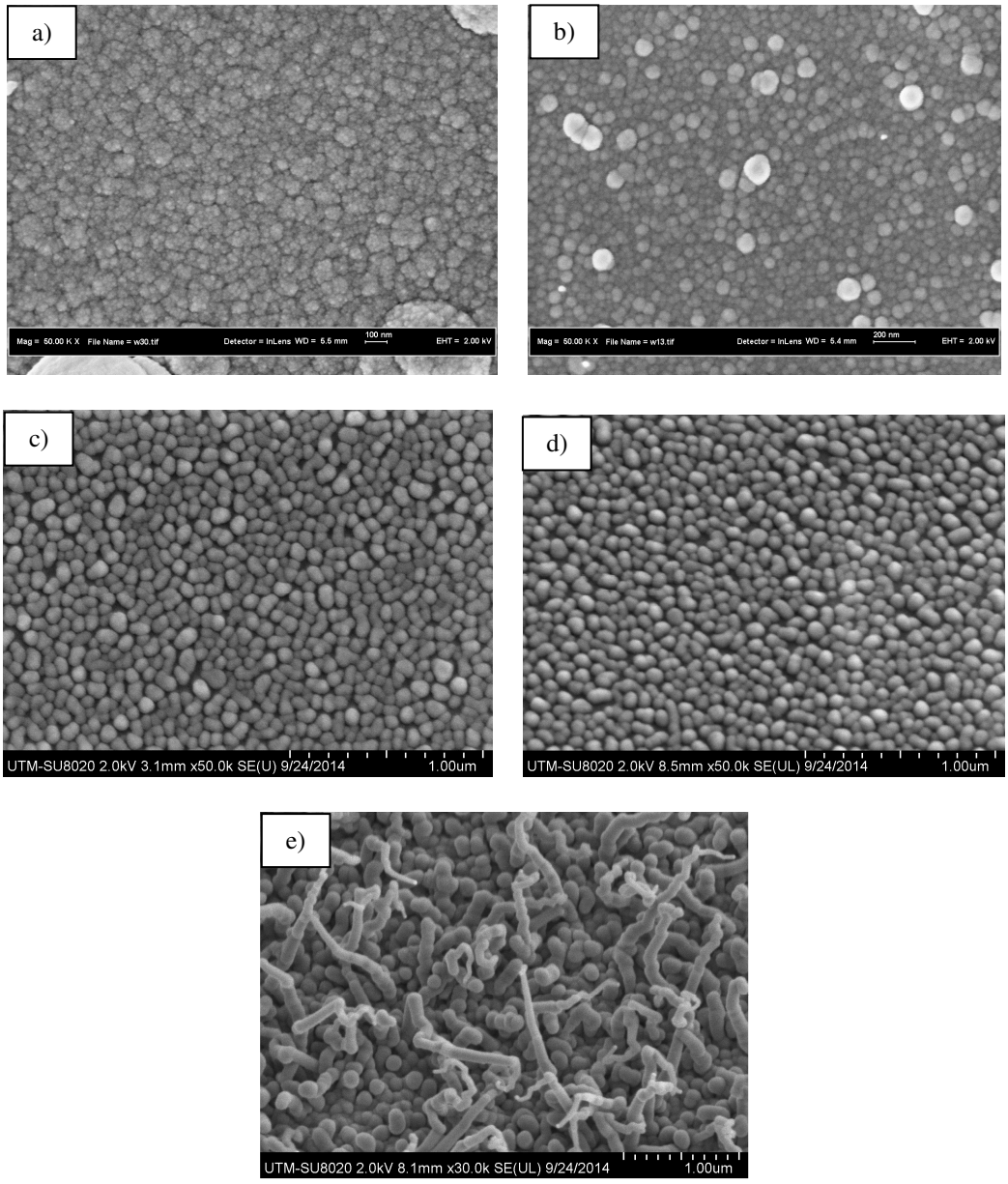

Figure 1: FESEM micrographs of as-prepared samples (a) S1, (b) S2, (c) S3, (d) S4 and (e) S5

As evident from the first two images (sample S1 and S2), the relatively poor morphology of samples S1 and S2 is solely due to the facile experimental

conditions where no hydrogen was used. These two samples were fabricated with 5 sccm of silane at 10 minute deposition time at 300 ºC and 400 ºC respectively. Conversely, the other three samples (S1 to S3) show excellent morphology after raising the temperature to 500 ºC and inserting hydrogen at 300 sccm into the chamber during deposition. Sample 3 reveals the appearance of individual silicon nanodot (Figure 1 (c)). As the deposition time and temperature were further increased to 30 minute and 500 ºC, respectively the silicon thin film with dots transformed to ball-like structures (Figure 1 (d)). Furthermore, the increase of the deposition time up to 1 h caused the formation of Si-NWs structures (Figure 1 (e)).

The liquid-vapour-solid (VLS) mechanism is responsible for the NWs growth [14]. In this mechanism, Au is firstly gets deposited on the silicon wafer substrate. As the temperature is increased at 363 ºC, small liquid of Au-Si alloy droplets is formed on the surface. The molecules of precursor gas upon injection cracked down on the surface of Au-Si alloy. This droplet of precursor gas became supersaturated until silicon freezes out at the silicon/droplet interface. Continuation of this process leads to the growth of nanowires [14].

The appearance of highly roughened surface morphology in Figure 1 (a) is ascribed to the effects of low temperature. From the theory of VLS mechanism, the temperature in which the Au-Si alloy is form should be above 363 ºC which explains the smoother thin film surface in Figure 1 (b), (c) and (d). Moreover, introduction of hydrogen during deposition process (Figure 1 (c), (d) and (e)) gives rise to the appearance of individual silicon dot. Previous study reported that introduction of hydrogen during deposition inhibits the formation of Si oxide on the film [13]. In plasma environment, hydrogen molecules are dissociated by high-energy electrons to form highly reactive species including H_2^*, H_2^+ , H, H^+, etc. [15]. These species in turn reacting with the hydrogen that exists in the precursor leads to the formation of Si NWs. However, deposition times such as 10 and 30 minutes are not enough for the droplets to become supersaturated. It is noticeable that when the deposition time is increased to 1 h the super-saturation process of silane begins which finally produces Si-NWs on the film.

4.0 CONCLUSIONS

The formation of high quality Si-NWs is demonstrated. The VHF-PECVD fabrication parameters dependent silicon thin film production is inspected. Samples are grown on Si(100) substrate with gold (Au) catalyst, silane gas precursor and hydrogen injection. Fabrication parameters such as deposition time, temperature and the rate of flow of the precursor gas are controlled to achieve the optimized growth condition. The FESEM images displayed the formation of Si nanodots and subsequent transformation to NWs with the control of growth parameters. The deposition temperature, time and the amount of hydrogen flow played a significant role in the formation of NWs via VLS mediated growth mechanism. The deposition parameters dependent morphological transformation may constitute a basis for the production of high quality Si-NWs. It is asserted that 10 sccm of silane, 300 sccm of hydrogen, temperature 500 ºC, and 1h of deposition time is the optimized parameter for Si NWs fabrication.

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